VOLUME 76 SEPARATE No. 1

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

FEBRUARY, 1950

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

IMPROVEMENTS AT THE BACK RIVER SEWAGE WORKS, BALTIMORE, MD.

By C. E. Keefer, M. ASCE

SANITARY ENGINEERING DIVISION

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

AMERICAN SOCIETY OF CIVIL ENGINEERS
Founded November 5, 1852

PAPERS

IMPROVEMENTS AT THE BACK RIVER SEWAGE WORKS, BALTIMORE, MD.

By C. E. Keefer,[1] M. ASCE

Synopsis

The history of practically all large sewage works that have been in service for any considerable period has been that improvements and additions are required from time to time. In some instances, the need for these additions has been caused by an increase in sewage flow or organic load. In other cases, old treatment units have outlived their efficient usefulness and have been replaced by more modern equipment. The work described in this paper falls into both categories. During the 18-year period from 1930 to 1947, inclusive, $3,859,500 was spent on new improvements at the Back River sewage works in Baltimore, Md., which serves most of the city and a considerable section of the Baltimore County Metropolitan District adjacent to the city. This project provides for primary and secondary treatment of the sewage and includes: (1) A building with mechanically cleaned bar screens; (2) three grit chambers; (3) five preliminary settling tanks; (4) activated-sludge units; (5) equipment for chlorinating the final effluent; (6) a sludge control station containing pumps for handling raw and digested sludge and gas boilers for heating the digestion tanks, together with metering equipment used in conjunction with the operation of the sludge tanks; (7) five covered sludge digestion tanks; (8) a 200,000-cu-ft gas holder; (9) four vacuum filters; (10) an electric substation; and (11) the necessary sewer conduits and pipe lines connecting these improvements.

Introduction

Before 1906 Baltimore was one of the few large cities in the United States without a sewerage system. At that time the city was provided with several storm drains which discharged into the harbor. In most cases these were far from adequate. In part of the business section of the city and in a few of the

Note.—Written comments are invited for publication; the last discussion should be submitted by July 1, 1950.

[1] Deputy Sewerage Engr., Bureau of Sewers, Baltimore, Md.

better residential districts the sewage flowed through sewers, which emptied into the storm drains or streams tributary to the harbor.

By far the larger part of the city, however, had no sewers. There were more than 90,000 cesspools in the city in 1906, many of which were not regularly cleaned, with the result that they overflowed into alleys and streets. Furthermore, the wastes from kitchen sinks, bathtubs, and lavatories flowed down the streets to the nearest inlet. These polluting liquids eventually reached the harbor, a landlocked body of water, which frequently gave off considerable stench. This condition had existed for years until, in 1904, the first allotment of \$10,000,000 was obtained for building a sewerage system, which included a sewage treatment works. A plant was constructed for separate sludge digestion, with sedimentation tanks and trickling filters, at a cost of \$2,777,000 and was put in service in 1911.

During World War I, and immediately thereafter, practically no construction work was done at the sewage plant. However, from 1920 to 1930, a number of additions were made, consisting of a preliminary settling tank, sludge digestion tanks, sludge drying beds, and three pumping stations to handle sludge and the drainage from sludge beds. Several buildings for miscellaneous purposes were constructed, and other important work was completed; but, much remained to be done.

The Sewage Treatment Works.—The sewerage system of Baltimore is of the separate type. The topography of the city is such that approximately 64% of the sewage flows by gravity to the sewage works. The remainder is pumped into the outfall sewer, which has a capacity of 291 mgd.

The flow increased from 55.09 mgd in 1925 to 60.65 mgd in 1930, the year when the improvements described in this paper were begun. The sewage is domestic in character with a relatively high biochemical oxygen demand (B.O.D.) and suspended solid content. When it reaches the treatment works it is in a stale condition.

The plant (Fig. 1) is situated on a tract of land containing 547 acres, about 2 miles east of the eastern boundary of the city on the west shore of Back River, a tributary of Chesapeake Bay. The sewage formerly entered the treatment works at a screen house, which was provided with two rows of bar screens with $\frac{7}{8}$-in. clear openings. From the screen house the sewage flowed to four manually cleaned preliminary settling tanks, each with a capacity of 3,800,000 gal. Each group of two tanks was provided with a vertical, centrifugal pump for removing supernatant and sludge from the tanks. During periods of normal flow two tanks were in operation while the other two were being cleaned. The effluent from the settling tanks entered a building containing drum-type revolving screens, wrapped with No. 20 mesh, Monel metal, wire cloth. The screened effluent then flowed to the trickling filters, which cover 30 acres and are 8.5 ft deep. The filtered effluent is settled in two humus tanks and then flows through two 60-in., wood stave, circular conduits into the Back River.

The sludge from the preliminary settling tanks and the humus tanks was pumped into fifty-one open digestion tanks with a working capacity of 2,406,700

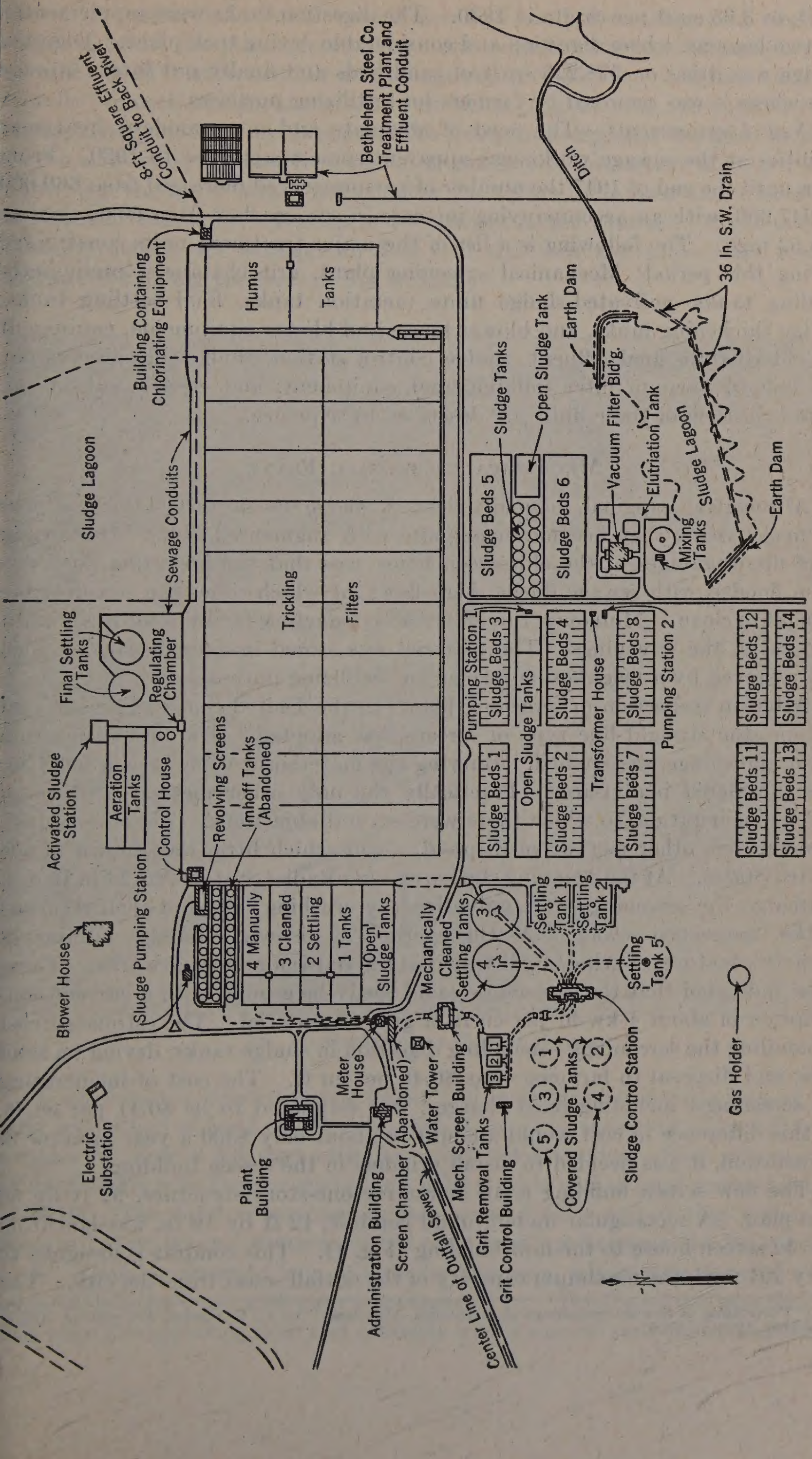

Fig. 1.—Back River Sewage Works, Baltimore, Md.

cu ft, or 3.65 cu ft per capita in 1930. The digestion tanks were supplemented by two lagoons, where digestion and considerable drying took place. Digested sludge was dried on 578,223 sq ft of sand beds and finally put into a storage pile where it was removed by farmers for fertilizing purposes.

New Improvements.—The need of adequate and more modern treatment facilities at the sewage works was apparent some years prior to 1930. From then until the end of 1947 the number of persons served increased from 660,000 to 947,600, with an accompanying increase in sewage flow from 60.65 mgd to 118.52 mgd. The following is a list of the major treatment units constructed during this period: Mechanical screening plant, grit chambers, preliminary settling tanks, activated-sludge units (aeration tanks, final settling tanks, sludge thickening tanks, and blower house and blower equipment), equipment for chlorinating final effluent, sludge control station, sludge digestion tanks, gas holder, vacuum filter building and equipment, and electric substation. Details of each of these units are described in sequence.

Mechanical Screening Plant

Although the original, manually cleaned, coarse screens served their purpose for many years, they became inadequate with augmented flows. One of the chief disadvantages of the old screen house was that the operating floor was often flooded with sewage during high flows, at which times the screens were difficult to clean. Moreover, there were no satisfactory facilities for the prompt disposal of the screenings. The material was stored in a small wooden shed and removed by a neighboring farmer for fertilizing purposes.

After an inspection of screening plants in the United States, Canada, and Europe, the straight-line type of screens was adopted. The best disposition of the screenings was studied. Burying the material or using it as a fertilizer was considered inadvisable. Practically the only other method of disposal was by incineration, to which there were several objections. There remained, however, one other method of disposal, about which little was known in the United States. At the pumping station serving Radial System No. 11 in Berlin, Germany, the screenings were pulverized by crushing rolls and then returned to the unscreened sewage. As this method of disposal offered a number of attractive features, a grinder was tested at the Baltimore sewage works. These tests[2] indicated that the screenings could easily be ground with a current consumption of about $\frac{1}{4}$ kw-hr per cu ft of ground material. The estimated cost of handling the screenings—including digestion in sludge tanks, drying on sand beds, and disposal to farmers—was \$0.46 per cu ft. The cost of incinerating the screenings, including fixed charges, was estimated to be \$0.41 per cu ft. As this difference in cost would amount to about only \$300 a year in favor of incineration, it was decided to install grinders in the screen building.

The new screen building is an attractive one-story structure, 92 ft by 50 ft in plan. A rectangular underground conduit, 12 ft by 10 ft, was laid from the old screen house to the new building (Fig. 1). This conduit is designed to carry 291 mgd, the maximum capacity of the outfall sewer from the city. The

[2] "Pulverizing of Sewage Screenings at Baltimore, Maryland," by C. E. Keefer, *Proceedings*, ASCE, September, 1929, p. 1759.

conduit separates into three covered channels just before connecting with the building below the ground; and they unite with three screen chambers, each of which is 10 ft wide and has an average depth of 13.5 ft. A screen has been installed in each of the channels, two of which (Fig. 2) were provided in 1932, immediately upon the completion of the screen building, and the third in 1937. In the walls of each channel on the upstream side of the screens there is a weir, 14 ft long, the top of which is 2 ft below the screen room floor and 6 in. above the normal maximum elevation of the sewage in the channel. If the screens become clogged, the sewage can flow over this weir and around the screens instead of flooding the floor of the building.

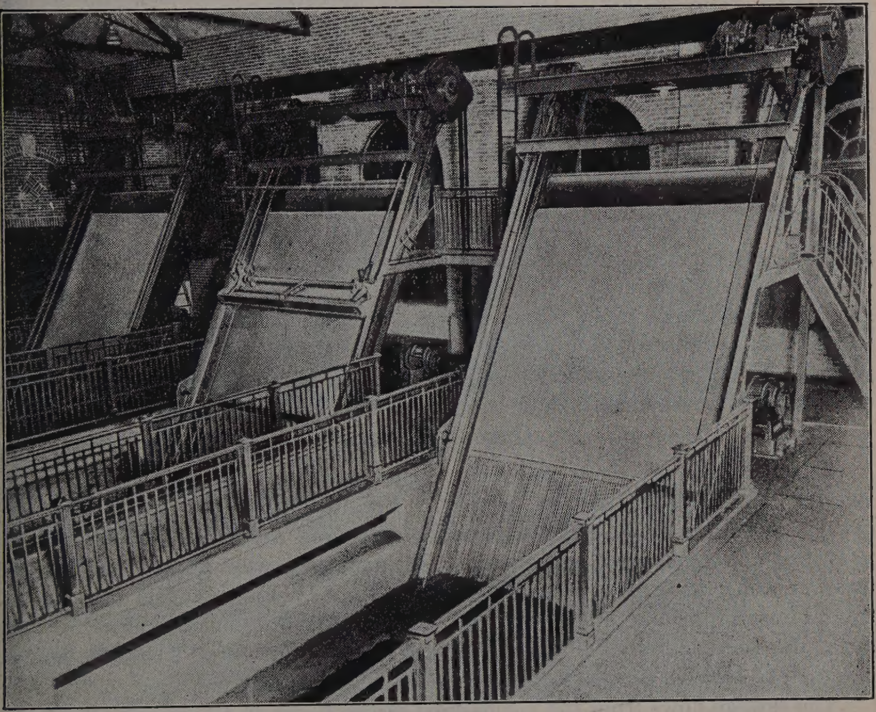

Fig. 2.—Mechanically Cleaned Screens

Each screen is cleaned mechanically and is designed to treat a flow of 150 mgd with a loss of head of not more than 6 in. The screening plant will treat a maximum flow of 300 mgd with one screen out of service. Each screen is set at a 60° angle with the horizontal and is 10 ft wide with a total vertical height of 29 ft. The total submerged surface area of each unit during maximum flows is 123 sq ft, and the area of the clear openings between the bars is 81.4 sq ft. Genuine wrought iron is used for the bars, which have tapered cross sections, 3 in. by $\frac{3}{8}$ in., with clear openings of $\frac{3}{4}$ in. The top of the bars terminates near the operating floor and connects with a smooth steel plate, which is in

the same plane with the bars. The screens are pivoted just above the operating floor so that they can be lifted above the sewage in case repairs are necessary.

A mechanically operated rake is provided to clean each screen. The screenings are dragged up the bars and over the surface of the dead plate into a vertical hopper. Solenoid operated valves admit water under pressure into each hopper just prior to the discharge of the screenings into the hopper. The bottom of each hopper connects with a pulverizer with a capacity of 1.5 tons per hr. Each of the first two grinders that were installed was driven by a 25-hp motor at a speed of 1,140 rpm. Experience with these units indicated that better results would have been obtained if they were operated by larger motors at a higher speed. Therefore, the third grinder was provided with a 30-hp motor, running at a speed of 1,760 rpm. The grinders are watertight to prevent the escape of water, which flushes the pulverized material through the machine into the sewage on the downstream side of the screens. Each screen is driven by a 4-hp motor and was designed to be started automatically or manually. Each cleaning cycle of the screening rake takes from about 5.5 min to 6 min.

Stop planks of steel construction, in double grooves, are provided in the conduits upstream and downstream from the screens. Experience indicates that single grooves for stop planks would have been equally satisfactory with an appreciable saving in the size and the cost of the building. Office, toilet, storage, and transformer rooms have been built. With the exception of the office and the toilet rooms the building as originally designed was not heated. However, as considerable condensation collected on the walls and on the mechanical equipment, two unit gas heaters were later provided to correct this condition. A 3-ton traveling crane has been installed for handling stop planks and parts of the screens.

Grit Chambers

When the sewage plant was first constructed, no provision was made to remove grit from the sewage, primarily because Baltimore has a separate system of sewers. Operating experience gradually indicated the wisdom of providing grit removal equipment. Construction was finally started in October, 1937, on three grit removal tanks (Fig. 3). Each tank is designed to treat a maximum flow of 100 mgd with a theoretical detention period of 100 sec at the aforementioned flow. Each tank is 50 ft square and 9 ft deep, and is designed to remove particles approximately 0.25 mm in size.

The sewage flows from the mechanical screen building to the grit chambers in a reinforced-concrete box conduit, 12 ft wide by 10 ft high. This conduit unites with three smaller conduits, each 8.5 ft wide by 7.58 ft high, through which the sewage flows to the grit chambers. A motor-operated, steel sluice gate, 84 in. by 84 in., is provided in each conduit for controlling the flow to the grit chambers. The effluent from each tank discharges through a covered conduit, 8 ft by 8 ft, in which there is a motor-operated steel sluice gate. These three conduits discharge into a concrete conduit, 12 ft by 10 ft.

A rotating mechanism, supported at the center of each grit chamber and also on the tank walls, squeegees the deposited material to a classifier just outside the tank, which separates the organic solids from the inorganic solids.

The former material is moved up a concrete incline and discharges on a horizontal belt conveyor 14 in. wide. This conveyor terminates in a near-by, one-story brick building, which contains a bucket elevator for discharging the

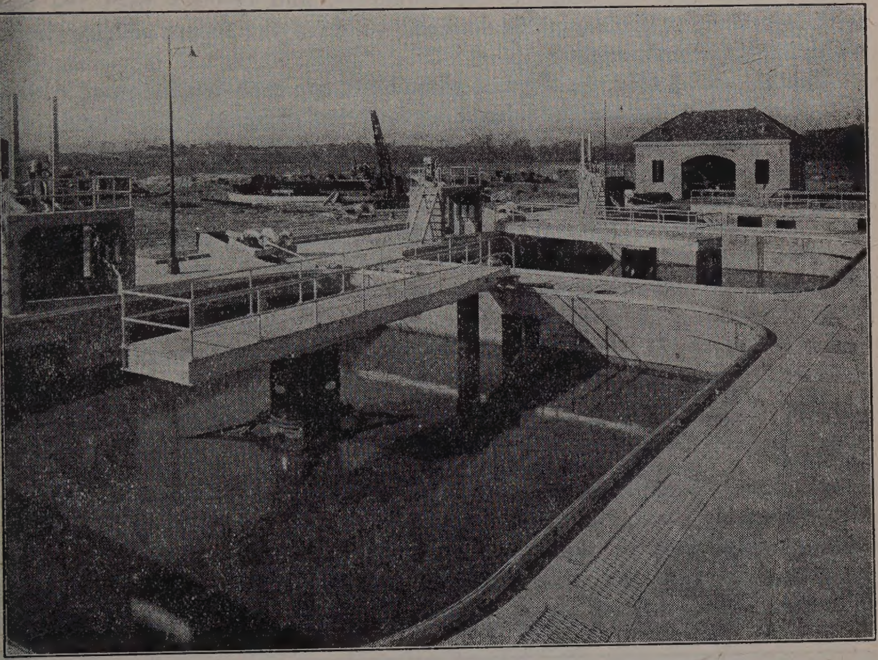

FIG. 3.—VIEW FACING WEST TOWARD GRIT CHAMBERS AND GRIT CONTROL BUILDING

grit into trucks, a control room with the necessary electrical apparatus to operate the grit removal equipment, and a driveway for the trucks.

PRELIMINARY SETTLING TANKS

The four manually cleaned preliminary settling tanks, three of which were put in service in 1911 and the fourth in 1921, were inadequate for a number of reasons. As they were cleaned manually, they had to be taken out of service to remove the sludge; consequently, twice the number of units was required. Furthermore, they were cleaned once every 4 or 5 days, whereas for the best results the sludge should have been removed as soon as it collected. The retention of this material in the tanks had a deleterious effect on the effluent. Moreover, the pH-value of the sludge decreased from 6.8 or 7.0 to 4.9 or 5.0 by the time it was removed. This acid condition made the material difficult to decompose, and required more digestion space. The preliminary settling tank layout includes six tanks, each capable of treating an average flow of 25 mgd with a theoretical detention period of 2 hours and a maximum flow of 50 mgd. The construction of five of these tanks was begun in 1930 and completed in 1938, providing for an average flow of 125 mgd and a maximum flow of 250 mgd.

The sewage flows to these tanks from the grit chambers first through a conduit 12 ft wide by 10 ft high and then through five concrete pipes, each 54 in. in diameter. These pipes pass through the basement of the sludge control station, to be described subsequently, and connect with the five settling tanks. A sixth pipe is designed to serve the future settling tank, which is being constructed.

Tanks 1 and 2 (Fig. 4), the first to be built, are each 140 ft square with a water depth of 13 ft along the sides and a freeboard of about 2 ft. The surface loading during average flow conditions (Table 1) is 1,280 gal daily per sq ft of tank surface. Where the influent pipes (which are 30 in. in diameter) connect with the basins, manually operated sluice gates have been installed for regulating or shutting off the flow. After passing through these gates, the sewage enters narrow channels along the wall adjacent to the inlet side of each tank. One side of each channel has an adjustable submerged weir, over which the sewage discharges into the tank. The opposite wall of the tank is also provided with adjustable weirs. The lengths of the inlet and the outlet weirs in each basin are 78 ft and 102.5 ft, respectively, or 55.7% and 73.2% of the

TABLE 1.—Basis of Design, Preliminary Settling Tanks (Flow to Each Tank, 25 MGD, and Theoretical Detention Period, 2 Hours)

Rates	Tank Nos.	
	1, 2	3, 4, 5
Settling rate, in gallons per square foot per day	1,280	1,085
Effluent overflow rate, in thousand gallons per day per foot of weir	244	46.5

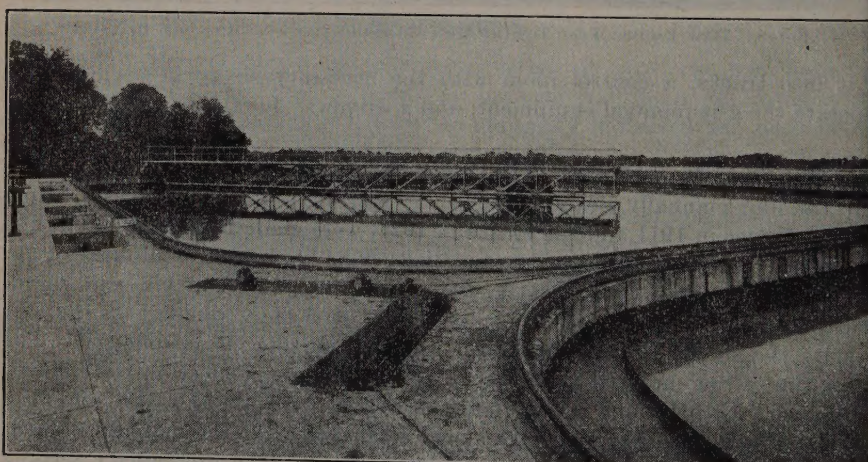

Fig. 4.—Preliminary Settling Tanks 1 and 2

idth of each tank. The effluent overflow rate is 244,000 gal daily per ft f weir.

Each basin is provided with mechanically operated equipment for removing udge continuously. This equipment consists of steel truss work, which carries he scraping blades for moving the settled sludge to the sludge discharge pipe t the center of the tank. Each clarifier is equipped with facilities for the ontinuous skimming of sewage. Attached to one side of the tank mechanism n a level with the surface of the sewage there is a vertical steel plate, 8 in. ide, which skims the surface as the mechanism revolves.

The bottoms of the tanks are constructed of plain concrete in two layers, he lower being 5 in. thick and the upper 3 in. thick. The floor slopes toward he center of the clarifier with a fall of 1 on 12. An 8-in., cast-iron discharge ipe connects with a depression at the center of the tank. The outer walls of he tanks, against which there is backfill, were designed to resist the horizontal hrust of the sewage with the backfill removed. In order to resist the de-eriorating action of the elements, especially at the surface of the sewage, he upper 4.5 ft of all the concrete walls was made of a richer mix, consisting f 1 part of cement and 4¾ parts of aggregate.

The construction of preliminary settling tanks 3 and 4, Fig. 1 (which were uilt under the same contract), was begun in February, 1936, and completed in anuary, 1937. Each of these tanks is 170 ft in diameter, with a sewage depth f 12.5 ft at the walls and a freeboard of 2 ft. These tanks have a surface load-ig of 1,085 gal daily, per square foot of surface, during average flow conditions. he sewage enters each tank through a 66-in., pre-cast, reinforced-concrete onduit, which is under the tank floor and terminates at the center of the tank a 54-in., vertical conduit. The sewage discharges into the tank through motor-operated plug valve at the top of this conduit and flows radially out-ard to the effluent weir. The rate of discharge over the weir is 46,500 gal aily, per foot of weir. A structural steel bridge or walkway is supported on the forementioned conduit and on the tank wall. The conduit also supports a otating mechanism which squeegees the sludge to the center of the tank. he tank floor (which is 8 in. thick) slopes toward the center of the tank, with fall of 1 on 12. A 12-in., cast-iron sludge pipe connects the center of each ettling tank with the sludge control station to be described subsequently. cum is removed by a skimming device which is partly submerged in the wage and is supported and driven by the sludge cleaning mechanism. It tends radially inward from the tank wall and forces the scum ahead of it it rotates about the tank center.

Preliminary settling tank 5 is similar to tanks 3 and 4. Construction work this tank was begun in August, 1937, and completed in October, 1938. It as put in operation in December, 1938.

Activated-Sludge Units

After considerable preliminary study it was decided, in 1937, to add to e facilities for oxidizing the preliminary settling tank effluent. For some ears prior to that time it was frequently necessary to by-pass a portion of the

settled sewage around the trickling filters. This practice was followed whe[illegible] ever the rate of flow exceeded about 110 mgd, the maximum capacity [illegible] the filters.

The requirements in favor of additional trickling filters as against activate[illegible] sludge units were studied. The use of activated-sludge units was approved f[illegible] two reasons: In the first place, as the area adjacent to the sewage plant w[illegible] changing from a rural to a suburban community, it was considered advisab[illegible] to construct treatment facilities that would be free from objectionable odo[illegible] Secondly, the effluent from activated-sludge units is better than that fro[illegible] trickling filters. It has always been the purpose of the City of Baltimore [illegible] produce an effluent with a high degree of purity in order to protect the wate[illegible] course into which it flows. Therefore, it was considered more advisable [illegible] build the activated-sludge units.

The basic data used in the design of the activated-sludge units are as follow[illegible]

Item	Description	Quanti[illegible]
0	Sewage flow, in million gallons per day—	
1	Average	20
2	Maximum	40
	Aeration Tanks (Spiral Flow)—	
3	Number of tanks	2
4	Theoretical detention period (based on an average sewage flow plus 25% of return sludge), in hours	5
5	Average solids content, in percentage of mixed liquor	0.3[illegible]
	Volume of Return Sludge (Based on Average Sewage Flow), in Million Gallons Daily—	
6	Average (good sludge with 1.5% solids)	5
7	Maximum (bulked sludge with 0.75% solids)	10
8	Installed output of air (three blowers) with sewage flow of 40 mgd, in cubic feet per gallon	1.7[illegible]
	Final Settling Tanks—	
9	Number of tanks	2
10	Theoretical detention period (based on an average sewage flow plus 25% of return sludge), in hours	2.4[illegible]
11	Surface loading (based on an average sewage flow plus 25% of return sludge), in thousand gallons per square foot per day	1
12	Effluent overflow rate, in thousand gallons per foot of weir, per day	26.2[illegible]
13	Assumed removal of suspended solids, in parts per million	60
	Activated Sludge Withdrawal, in Million Gallons Daily—	
14	Average (good sludge with 1.5% solids)	5.0[illegible]
15	Maximum (bulked sludge with 0.75% solids)	10.1[illegible]
	Excess Activated Sludge (Based on Average Sewage Flow), in Thousand Gallons Daily—	
16	Average (good sludge with 1.5% solids)	80

em	Description	Quantity
7	Maximum (bulked sludge with 0.75% solids)	160
	Sludge Concentration Tanks—	
8	Number of tanks	2
	Average Volume of Excess Sludge (One Tank in Service)—	
9	Theoretical detention period, in hours	13.75
0	Surface loading, in gallons per square foot per day	300
1	Solids, in percentage of the concentrate	4
	Maximum Volume of Excess Sludge (Two Tanks in Service)—	
2	Theoretical detention period, in hours	24
3	Surface loading, in gallons per square foot per day	300
4	Solids, in percentage of concentrate	4
5	Depth of tank allowed for supernatant, in feet	3
6	Average volume of thickened excess sludge (4% solids) to be pumped to raw sewage or to digestion tanks (based on treating an average flow of 20 mgd of sewage), in million gallons per day	30
7	Average volume of supernatant from thickened excess sludge (based on treating an average flow of 20 mgd of sewage), in million gallons per day	50

he plant was designed to treat an average flow of 20 mgd and a peak flow of 0 mgd (items 1 and 2). The trickling filters along with these units could hen treat an average flow of 130 mgd and a maximum flow of 150 mgd. The ctivated-sludge units were designed so that an average flow of 40 mgd could e treated by constructing additional units at a later date.

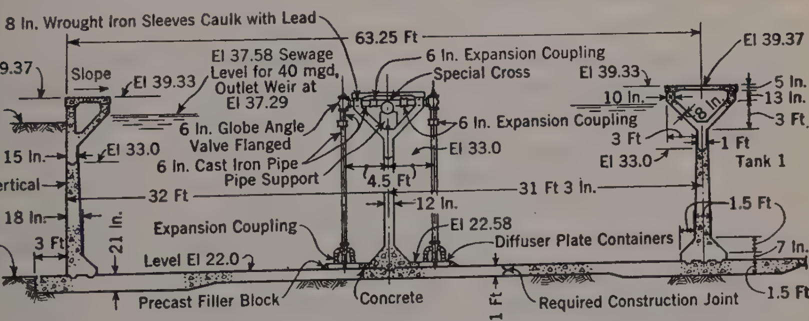

Fig. 5.—Cross Section of Aeration Tank

Aeration Tanks.—The activated-sludge plant consists of two aeration tanks, wo final settling tanks, an activated-sludge station, two sludge thickening anks, an operating gallery, and a blower house. Each aeration tank (Fig. 5) which contains two "flow-through" channels, each 30.25 ft wide) is 383 ft long vith a working depth of 15.29 ft. The settled sewage and the return activated ludge enter the inlet end of each tank through two cast-iron elbows, and the nixed liquor discharges over a weir, 37.28 ft long. The plant is designed on the

basis that normally the return sludge will contain 1.5% solids and will amount to 25% of the sewage flow, and that, during periods of bulking, the sludge will contain 0.75% solids and will amount to 50% of the sewage flow. With a sewage flow of 20 mgd the volumes of sludge under the aforementioned conditions are 5 mgd and 10 mgd, respectively (items 6 and 7).

The aeration tanks have an average theoretical detention period of hours (item 4) and are of the spiral-flow type. Each tank contains four vertical concrete cross baffles, each 12 ft wide, extending the full depth of the tank. Their function is to prevent unaerated mixed liquor from forming along the horizontal centers of the tanks.

Two rows of diffuser plates are provided on the bottom of each tank adjacent to one wall. Each tank contains 1,232 diffusers (12 in. by 12 in.) made of fused crystalline alumina grains. The plates have a permeability rating varying from 36 to 44 with an average of 40. The ratio of tank sewage surface area to plate area is 15.6. The diffuser plates are retained in a bed of cement mortar in pre-cast concrete plate holders by three-pronged malleable iron clamps. The air pipe supplying the plates in each tank is cast iron and varies in diameter from 12 in. to 20 in. This pipe is supported in a V-shaped valley in the top of the longitudinal wall extending through the center of each tank. From this pipe, 6-in., vertical, cast-iron pipes carry the air through 3-in. cast-iron pipes to the diffuser plate holders. The diffuser plates were installed so that the permeability rating of all the plates served by the same vertical air pipe varied as little as possible to insure that each plate in adjacent plate holders would pass essentially the same amount of air.

Final Settling Tanks.—East of the aeration tanks are two final settling tanks (see Fig. 1). Each is 126 ft in diameter with a water depth of 13.33 ft along the sides and a freeboard of 2.52 ft. The effluent from the aeration tanks flows first to a common aerated open channel and then through two 42-in. cast-iron pipes to the centers of the final settling tanks. When the sewage flow averages 20 mgd (to which 5 mgd of activated sludge is added), the average theoretical detention period in the tanks is 2.4 hours and the surface loading is 1,000 gal per sq ft per day (items 10 and 11). The effluent overflow rate amounts to 26,200 gal daily per foot of weir during average flow conditions (item 12). Each tank was provided with two pairs of submerged photoelectric cells which can be set at any suitable elevation. The purpose of these cells was to determine the depth of sludge in the tanks. The effluent from each tank discharges through a 3-ft-square, reinforced-concrete conduit and then discharges into a larger conduit.

The volume of activated sludge that collects in the settling tanks was assumed to be 5.08 mgd with the sludge in good condition (containing 1.5% solids) and with a sewage flow of 20 mgd (item 14). This volume consists of 5.0 mgd of return sludge and 0.08 mgd of sludge resulting from the removal of 60 ppm of suspended solids from the sewage (item 13), leaving 10 ppm of suspended solids in the final effluent. When the sludge is bulked with an assumed solid content of 0.75%, the volume of activated sludge would be double the aforementioned amount, or 10.16 mgd (item 15).

The activated sludge, which settles in the final tanks, is squeegeed to the center of each tank by a mechanism that makes 1 revolution in 40 min. The sludge flows through an 18-in. cast-iron pipe, one from each tank, into a suction well in the activated-sludge station adjacent to the aeration tanks. Each pipe line contains a rate controller for regulating the flow of sludge. Two centrifugal pumps, with a rated capacity of 5.2 mgd each, lift the activated sludge from the suction well into an upper chamber, whence it flows through two 18-in. cast-iron pipe lines (each of which contains a rate controller) to the two aeration tanks.

Sludge Thickening Tanks.—From the aforementioned upper chamber the excess activated sludge flows through a 6-in. cast-iron pipe line to two thickening tanks. These tanks were designed to thicken 160,000 gal daily of excess sludge containing 1.5% solids (items 16 and 17). This quantity was assumed to result from the treatment of an average flow of 40 mgd of settled sewage. Under the aforementioned sludge flow conditions, with one tank in service, the theoretical detention period is 13.75 hours and the surface loading is 300 gal per sq ft per day. The volume of concentrated sludge pumped from the tank was assumed to be 60,000 gal daily containing 4% solids.

Each sludge concentration tank is 26 ft in diameter with a water depth of 16 ft along the sides. Sludge enters each tank at the center, and the effluent discharges over a V-notched weir at the periphery. The effluent flows to two centrifugal pumps, one of which is a spare, and is lifted into the influent channel to the activated-sludge plant. The sludge is thickened in the aforementioned tanks by a picket-fence mechanism. The thickened sludge flows to two reciprocating pumps (variable speed), each of which has a maximum capacity of 140 gal per min and is pumped through a 6-in. cast-iron force main either into the raw sewage ahead of the preliminary settling tanks or into the raw-sludge suction well of the sludge control station.

To prevent the activated sludge from becoming septic in the thickening tanks the supernatant in these tanks is chlorinated by two vacuum-type chlorinators, each capable of delivering from 15 lb per hr to 300 lb per hr of chlorine. The chlorine, dissolved in water, is introduced into each tank at eight points approximately 17 in. below the surface of the supernatant. To control bulking, chlorine can be added to the return activated sludge as it flows into the receiving well from the final settling tanks.

In the basement of the activated-sludge station a motor-driven centrifugal pump with a capacity of 5,400 gal per min is available for dewatering the aeration tanks and the final settling tanks. As there is a possibility of flooding the pumping unit if the piping in the aforementioned basement should break, the drive motor is designed to operate submerged under 15 ft of water.

The following venturi meter equipment was installed in the activated-sludge station:

1. Two meters, 36 in. by 18 in., for measuring the sewage flow to the aeration tanks;
2. Two rate controllers, 18 in. by 18 in., for measuring the return sludge flowing to the aeration tanks; and

3. Two rate controllers, 18 in. by 18 in., for measuring the sludge flowing from the final settling tanks.

Control tables, made of ebony-asbestos slabs, were provided on the main floor of the activated-sludge station. These tables (three in number) contain gages that indicate the flow of sewage, sludge, and air to each tank; the flow of return sludge from each of the final settling tanks; and the ratios of air to sewage and return sludge to sewage.

Immediately east of, and adjacent to, the aeration tanks there is a covered pipe gallery (Fig. 6) which joins the basement of the activated-sludge station. This gallery contains the sewage, sludge, air, and mixed liquor piping that connects with the various tanks. The sludge and other pumps are either in this gallery or in the basement of the activated-sludge station.

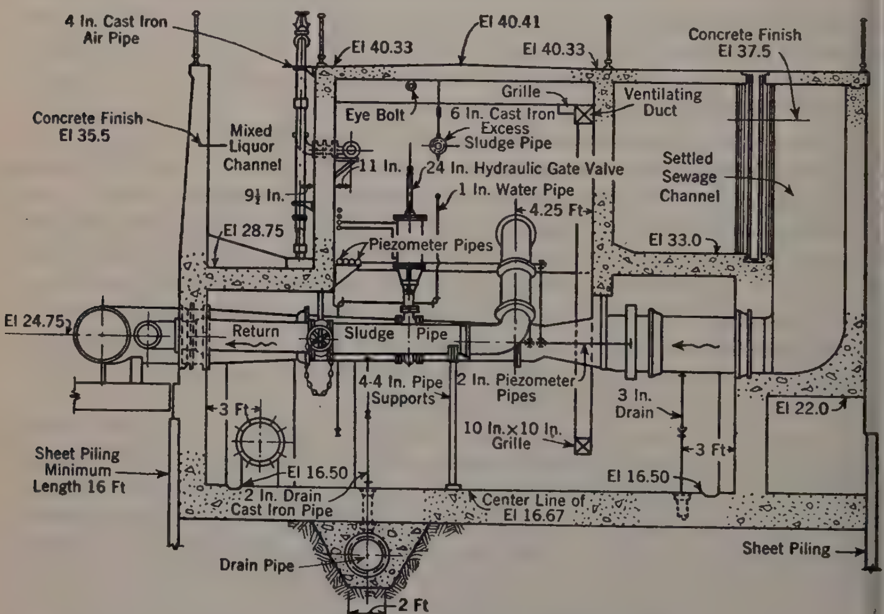

FIG. 6.—CROSS SECTION OF PIPE GALLERY, ACTIVATED-SLUDGE PLANT

Blower House and Blower Equipment.—Approximately 250 ft west of the aeration tanks a building was constructed to house the centrifugal blowers which furnish air to the aeration tanks. This building, a one-story structure, 94 ft by 80 ft in plan, contains three motor-driven centrifugal blowers with space for one future unit. Each blower delivers 16,500 cu ft per min of air against a pressure of 7.5 lb per sq in. With all three blowers in service 1.78 cu ft of air per gal of sewage is available at a peak sewage flow of 40 mgd. The blowers are direct connected to 2,300-volt, air cooled, squirrel-cage motors, operating at 3,600 rpm.

The air handled by the blowers enters the basement of the building and passes first through three primary filters and then through secondary filters. The primary filters, each with a capacity of 19,500 cu ft per min of free air, are of the automatic, viscous, impingement, self-cleaning type. The secondary filters are of the dry cellulose type with a capacity of 58,500 cu ft per min of free air. From the secondary filters the air flows through three 30-in. cast-iron pipes to the blowers. In each of these pipes there is a venturi tube with a maximum capacity of 20,000 cu ft per min of free air and a motor-operated intake throttling valve. The discharge pipe from each blower connects with a 42-in. cast-iron air main, which is laid underground to the aeration tanks. A 10-in., motor-operated gate valve is installed in the discharge pipe from each blower. This valve opens automatically when a blower is started and closes when full operating pressure is built up in the discharge pipe.

Auxiliary equipment used in conjunction with the lubricating system consists of three water cooled oil coolers, one for each of the blowers and a motor-driven centrifugal oil purifier.

A 125-volt, 60-cell storage battery with a 1-hour rating of 144 ampere-hr furnishes direct current to: (*a*) The solenoids in all the 2,300-volt oil circuit breakers, (*b*) the motors that operate to the valves in the suction and discharge piping leading to the centrifugal blowers, (*c*) the limit switches on these valves, and (*d*) the bearing thermostats on the motor-driven blower units. A 5-kw motor generator is used to charge the storage battery.

Equipment for Chlorinating Final Effluent

In order to reduce the bacterial load in Back River, the estuary into which the sewage effluent discharges, it was decided, in 1945, to provide chlorinating equipment for the final effluent during the warmer months of the year. A "rotometer" with a capacity of 6,500 lb per day was installed in an existing building adjacent to the effluent channel leading from the humus tanks, and two outdoor wooden platforms were erected to hold twenty-four 1-ton chlorine cylinders. Extra-heavy black steel pipe connects the chlorine tanks with the rotometer. The chlorine from the rotometer discharges through 1-in. piping to a water ejector and then through a 3-in. pipe suspended in the effluent channel. The chlorine, dissolved in water, flows from this pipe through sixty-four ¼-in. holes into the effluent.

In order that there would be no interruption in chlorinating the effluent a second rotometer of the same capacity as the first one was installed in 1946, and duplicate piping was provided from the chlorine cylinders to the discharge piping in the effluent channel. It is possible to segregate the chlorine cylinders into two groups and operate the rotometers in parallel, or chlorine from all the cylinders can be fed to one rotometer.

Sludge Control Station

About halfway between the preliminary settling tanks and the heated sludge digestion tanks, a sludge control station was constructed. The equipment in this station was designed to serve the aforementioned settling tanks

and five sludge digestion tanks. The piping and the apparatus in the building however, are arranged so that ultimately six settling tanks and eight digestion tanks can be served.

The basement of the building is sufficiently large to contain six venturi tubes, 54 in. by 30 in.; five of these have been installed to measure the sewage flowing to the preliminary settling tanks. Each meter is of a special design with its invert in the same horizontal line. This design was selected because it was feared that solids, which would roll along the bottom of the conduit leading to the meter, might be retained on the upstream side of the throat of the meter. A subsequent examination of the venturi tubes, 42 in. by 21 in., in service at the sewage works for twenty-five years indicated that this apprehension was unfounded. In the future, meters of a standard design will be used since they are considerably cheaper.

Brass pipes, $1\frac{1}{4}$ in. in diameter, connect the annular rings on the meters with 10-in., vertical, cast-iron float tubes. Crosses with removable plugs are provided at all changes in the line and grade of these pipes to facilitate cleaning. At the top of each float tube there is a pipe provided with a needle valve for continuously introducing a small stream of clean water into the tube.

At one end of the sludge control station there is a well, divided into two compartments. One compartment receives raw sludge from the settling tanks, and the other ripe sludge from the digestion tanks. From each of the settling tanks an 8-in. cast-iron sludge pipe connects with this well. Furthermore, a similar pipe, carrying scum from the settling tanks empties into the well. Each of these pipes connects with a wrought iron swivel pipe, the outer end of which can be raised to a level above the hydraulic grade in the settling tanks. The digested-sludge well is equipped with 10-in. swivel pipes of the same design as those in the raw-sludge well. Each pipe connects with a 10-in. cast-iron discharge pipe, terminating at the bottom of a sludge digestion tank.

Adjacent to the well there is a room, containing the pumping equipment. It is 55 ft by 22 ft in plan with a main gallery floor and a lower floor for the pumping equipment. There are seven horizontal centrifugal pumping units, all operated by 440-volt, alternating-current motors. Two of the pumps (which have a capacity of 350 gal per min) are used to handle raw sludge. By reducing the speed the capacity can be decreased to 75 gal per min or 100 gal per min. Each pump has sufficient capacity to handle the raw sludge from a sewage flow of 140 mgd. The pumps discharge into a 10-in. cast-iron force main, containing a venturi tube with a maximum capacity of 720,000 gal daily. The venturi tube connects with a cast-iron manifold, and 10-in. pipes (each containing an hydraulically operated gate valve) extend from this manifold to the digestion tanks.

There are also two centrifugal pumps for handling digested sludge. Each of these has a capacity of 1,000 gal per min. The sludge discharges through a 10-in. cast-iron force main that contains a venturi tube with a maximum capacity of 2.30 mgd.

All four sludge pumps are especially designed to permit the passage of 4-in. spheres. The discharge piping from each of the digested-sludge pumps is

designed so that sludge from the heated digestion tanks can be pumped to a vacuum filter building or into other tanks or lagoons for further digestion or storage. The sludge piping in the building is covered with wool-felt insulation, $\frac{3}{4}$-in. thick, to prevent condensation from forming on the pipes.

There are two centrifugal pumps, each with a capacity of 400 gal per min, which circulate hot water through pipe coils in the sludge digestion tanks for heating purposes. These two units can handle sufficient water to heat six sludge tanks, each with a capacity of 200,600 cu ft. It is planned, at some future date, to install eight of these tanks, and at that time the capacity of each hot water pump can be increased to heat the additional tanks by providing a larger impeller. Each unit is driven by a 3-hp motor, operating at a speed of 1,740 rpm. As the motor contains four independent sets of windings, the pump can also be run at speeds of 1,160 rpm, 870 rpm, and 580 rpm. These reduced speeds are used during warm weather when less heat is required.

On the gallery floor of the pump room there is a large switchboard on which electrical equipment and recording instruments are mounted. All pumping equipment on the lower floor is controlled from this switchboard. The recording instruments consist of liquid-level and methane recorders. The former record the level of the sludge in the digestion tanks, and the latter record the amount of methane in the gases evolved from each of these tanks.

The sludge control station contains a boiler room with equipment for heating the sludge digestion tanks; six gas-fired boilers have been provided, each with a capacity of 2,304,000 Btu per hr. The flues from the boilers are made of 12-gage copper.

The existing boilers generate low pressure steam, which passes to two heat exchangers. The return water from the digestion tanks is pumped through the heat exchangers by the hot water pumps in the pump room. Each heat exchanger is designed to heat 400 gal of water per min from 100° F to 136° F.

Meters are available in the boiler room for recording and registering the amount of water used to heat the sludge digestion tanks. Furthermore, there are electrically operated thermometers for recording the temperatures of the sludge in the digestion tanks, the heating water entering and leaving these tanks, and the outdoor atmosphere.

Adjacent to the boiler room is a room containing five 6-in., rotary-type, displacement gas meters, each with a normal capacity of 16,980 cu ft of gas per hr. The meters are designed to operate with the gas flowing in either direction. The advantage of this design is that, when sludge is being withdrawn from the digestion tanks, gas from the gas holder can flow back into the digestion tank through the gas meter. Thus, the formation of a vacuum or the sucking of air into the space below the roof of the digestion tank is obviated. Each digestion tank is provided with its own gas meter.

To guard against the possibility of a gas explosion in the sludge control station an electrically operated, combustion gas alarm was installed. Radiating from this alarm there are six $\frac{1}{8}$-in. copper pipes which terminate at various points in the building. A small pump forces the air adjacent to the open ends of the pipes to the combustion alarm, which rings a bell if any inflammable gas is present.

Sludge Digestion Tanks

Just west of the sludge control station five covered sludge digestion tanks have been built. The first two were constructed from 1933 to 1935; the third, from 1937 to 1939; and the last two, in 1946–1947. The basis of the design of these tanks is as follows:

Item	Description	Quantity
1	Capacity of each tank, in thousand cubic feet	200.6
2	Percentage of tank space occupied by sludge	80
3	Percentage of tank space occupied by supernatant liquor	20
4	Average moisture of sludge, in percentages	93
5	Quantity of dry solids in each tank, in thousand cubic feet	11.2
6	Moisture, in percentage of raw sludge added	95
7	Volatile matter, in percentage of raw sludge (dry basis)	75
	Quantity of Raw Solids Added Daily to Each Tank—	
8	In percentage of dry solids in tanks	4
9	In cubic feet (dry basis)	448
10	In thousand gallons (wet basis, containing 95% water)	67
11	Volume of gas produced, in cubic feet per pound of fresh volatile matter	7
12	Gas produced daily by each tank, in thousand cubic feet	150
13	Maximum gas production, in percentage of the average	250
14	Methane content of gas, in percentage of gas volume	70
15	Estimated number of persons served per tank, in thousands	242

As indicated, each tank has a capacity of 200,600 cu ft and was assumed to serve 242,000 persons (items 1 and 15). The raw sludge added to the tanks was estimated to contain 5% dry solids, 75% of which was considered to be volatile matter. The quantity of sludge added to each tank was estimated to be 67,000 gal daily, which was based on the dry solids added daily, amounting to 4% of the dry solids in the tank. It was assumed that 7 cu ft of gas would be produced per pound of fresh volatile solids added, or 150,000 cu ft daily per tank.

The tanks (Fig. 7) are 100 ft in diameter and 25 ft deep at the walls. Their roofs are made of reinforced concrete and rest on the tank walls and on concrete columns at the center. The roofs of tanks 1 and 2 differ somewhat from those of tanks 3, 4, and 5. Each roof is supported by thirty-two horizontal steel beams placed in a radial position with their outer ends resting on the tank wall. In tanks 1 and 2 these are 125-lb, 24-in. beams, terminating approximately 14.5 ft from the center of the tank and hung from sixteen structural steel vertical members. These latter members are supported by steel trusses, which in turn are secured to a steel column, resting on the central concrete column.

In tanks 3, 4, and 5, however, the horizontal steel beams are 36 in. deep and weigh 250 lb per ft. The inner end of each beam is supported by two $2\frac{1}{2}$-in. vertical steel bolts, which are suspended from a structural steel spider at a distance of 4.75 ft from the center of the tank. With this type of construction it is possible to suspend the stirring mechanism on a steel drum, which encloses the central column and passes through an annular slot in the tank roof.

This slot is provided with a cylindrical steel trough filled with water to prevent the escape of gas. The concrete roofs of the digesters were made quite thin to keep the dead load as light as possible. A vent in the roof made of 16-gage, galvanized sheet steel, with an opening 7 ft by 1.33 ft in plan, permits the escape of gas into a gas dome. There is a 6-in. cast-iron gas pipe from each digester to the sludge control station.

Each tank roof is covered with three-ply asphalt felt roofing to prevent the escape of gas. This roofing is covered with a layer of concrete 3 in. thick so that gas cannot get under the membrane and raise it; four ports, 12 in. in diameter, have been furnished in the roof for sampling the sludge.

FIG. 7.—INTERIOR OF SLUDGE DIGESTION TANK, CAPACITY, 200,600 CU FT

Since the foundation under the tanks consisted of soft muck, each central column rests on fifty-seven pre-cast concrete piles, 18 in. by 18 in., which support a maximum load of 4,088,000 lb. The tank walls are supported by two concentric rows of wooden piles, spaced 3 ft apart along the periphery of the tank footing. Tongue-and-groove sheet piling, 12 in. by 12 in., was driven around the outer edge of the footing to prevent the pressure of dirt around the digester from being transmitted to the soil beneath the tank floor and heaving the bottom. A layer of coarse gravel, approximately 15 in. thick, was provided under the entire tank floor. Cast-iron pipes, 6 in. in diameter, were laid in the gravel for drainage purposes. The floor of each digester consists of concrete 8 in. thick. A mechanism, which rotates about the vertical center line of the tank, is provided to stir the sludge gently and to force the digested material to the discharge pipe.

Adjoining each tank there is a manhole containing three 10-in. sluice gates, placed 12 ft, 16 ft, and 20 ft above the bottom of the tank for withdrawing

supernatant sludge liquor from different depths. There is also another manhole adjoining each tank, which contains a manometer for recording the elevation of the sludge in the digester. Digested sludge flows from the tank through a 10-in. cast-iron pipe to the sludge well in the sludge control station. Raw sludge is pumped to each of the tanks through two 8-in. cast-iron pipes laid on top of each digester.

Heat to Be Added to Digesters.—The following data relate to the heating of the sludge digesters. It was assumed that a temperature of 80° F would be maintained in the digesters in January, the coldest month in the year. The heat added is used to raise the temperature of the raw sludge pumped into the tanks and to compensate for losses by conduction. By far the larger amount of heat is required to raise the temperature of the incoming cold sludge. The heat needed for this purpose was estimated to be 831,000 Btu per hr and was based on the assumption that 23,750 lb of raw sewage at 45° F would be added hourly to each digester (based on daily additions equal to 4% of the dry solids in the digester). The temperature maintained in the digester was assumed to be 80° F.

The following is the estimated heat loss from each tank, in British thermal units per hour:

Through roof	99,000
Through walls	5,800
Through bottom	188,000
Total	292,800

The heat loss through the roof was based on an average air temperature of 34° F. Cost estimates were prepared to determine the desirability of insulating the roof with building tile or other insulating materials. The additional cost, however, was not compensated for by the value of the gas saved to heat the tanks.

In computing the heat loss through the tank walls the following formula[3] was used:

$$U = \frac{t_1 - t_2}{\dfrac{r_1 \log r_2/r_c}{k} + \dfrac{r_1 \log r_c/r_1}{k_c}} \qquad (1)$$

in which U is the heat transmission per square foot of tank surface per hour; t_1 is the temperature of the sludge in the tank (80° F); t_2 is the temperature of the ground at a distance, D, beyond the wall of the tank (45° F); r_1 is the radius of the inside of the tank (50 ft); r_c is the radius of the outside of the tank (51.75 ft); $r_2 = r_1 + D$ is the horizontal distance from the center line of the tank where the normal temperature of the ground is not affected by t_1 (91.75 ft); k is the conductivity of the ground (0.9 Btu per sq ft per hr per foot of thickness per 1° F temperature difference); and k_c is the conductivity of concrete (0.69 Btu per sq ft per foot of thickness per 1° F difference in temperature of the two surfaces).

[3] "Theory of Heat Losses from Pipes Buried in Ground," by John R. Allen, *Transactions*, Am. Soc. of Heating and Ventilating Engrs., Vol. 26, 1920, p. 335.

In computing the loss of heat through the bottom of the digesters it was assumed that the ground beneath them would not act as an insulator because there would be a flow of ground water through the drains under the tanks.

The area of heating coils in the digesters was based on the assumption that the heat transmitted through the pipe would be approximately 20 Btu per sq ft per hr per 1° F temperature difference between the inside and the outside of the pipe. The heating coil (which is 1,240 ft long and 6 in. in diameter) has an area of 1,975 sq ft. This pipe, unpainted, is hung in the form of a spiral on the inside of the digester about 2 ft from the walls. All the hot water piping (which is underground) from the sludge control station to the five digesters is insulated with asbestos sponge felt, 1 in. thick. The pipes are enclosed in reinforced-concrete conduits. Gravel and drain tile have been placed under these conduits to prevent ground water from backing up into them.

Gas Holder

A waterless gas holder was built with a capacity of 200,000 cu ft. The gas piping between the digestion tanks and the holder is designed so that gas will flow from the holder into the empty space formed below the digester roofs when sludge is drawn from the digesters. If a gas holder were not provided, a partial vacuum would be produced in the top of the digester and air would be sucked into this space with the danger of forming an explosive mixture of gas and air.

A waterless holder was constructed, because the cost of maintenance and operation is less than with a water-type holder. With the latter type provision must be made to heat the water in the seal cups and the tank. Furthermore, the painting of a water-type holder is much more of a problem.

The gas holder, which is built on a concrete foundation, is 63 ft 9 in. in diameter and 75 ft high at the eaves. The gas is stored under 8 in. of pressure below a circular piston, which moves up and down on top of the gas. The piston is made of $\frac{3}{16}$-in. steel plates, secured to steel trusses. Since it is very essential to know the quantity of stored gas, a gage has been provided on the outside of the holder and also in the sludge control station. An alarm rings if the quantity is less than 5,000 cu ft. On the 12-in. inlet pipe to the holder there is a gas burner. When the piston in the holder reaches its highest position, the burner ignites automatically and remains lighted until the piston has dropped 3 ft. In case the burner fails to light, the piston is forced upward by the gas, which escapes into the atmosphere through a series of holes in the shell of the holder.

Vacuum Filter Building and Equipment

In 1931 experiments were started at the Back River plant to determine if primary digested sludge could be dewatered on vacuum filters. After conducting extensive experiments for more than 2 years,[4,5,6] it was decided to use vacuum filters at the Back River plant.

---

[4] "The Dewatering of Sludge by Vacuum Filtration," by C. E. Keefer and E. C. Cromwell, *Sewage Works Journal*, November, 1932, p. 929.

[5] "Absorption and Flocculation As Applied to Sewage Sludges," by A. L. Genter, *ibid.*, July, 1934, p. 689.

[6] "The Vacuum Filtration of Elutriated Sludge," by C. E. Keefer and Herman Kratz, Jr., *ibid.*, September, 1934, p. 845.

The filter layout was designed to serve an estimated population of 1,200,00 in 1970 with a production of 60.5 tons daily (300-day operating year) of digeste dry solids. This quantity consists of 55 tons of digested primary sludge an 5.5 tons of digested activated sludge. The digested sludge was assumed t contain 4.0% dry solids.

The filtering equipment was installed in a one-story brick building, 97 f by 56 ft in plan. Two filters (Fig. 8), each with a surface area of 500 sq ft were initially provided in 1939, to be followed by two more filters of the sam size in 1946. Sludge from any of a number of open digestion tanks flows b gravity into a covered well in the basement of the filter building. Adjacen to this well there are three motor-driven centrifugal sludge pumps, each wit

Fig. 8.—View of Vacuum Filters, 500 Sq Ft

a capacity of 500 gal per min. These pumps deliver the sludge from the well through a 10-in. cast-iron force main (in which there is a venturi tube) into a tank equipped with a horizontal paddle mixer. A 20-in. cast-iron gravity pipe line connects the effluent channel of the trickling filters with this mixing tank. Sludge and filter effluent, which is used for elutriation purposes, can thus be mixed in this tank in almost any ratio. The mixture of sludge and filter effluent then flows to a circular elutriation tank, which is 80 ft in diameter and has a working depth of 15 ft at the side wall. This tank is designed to have a theoretical detention period of 4 hours with the upper 11.5 ft allotted for sedimentation and the lower 3.5 ft for sludge storage. Although only one tank was provided at first, it is planned to construct another of the same size in the future when larger volumes of sludge are dewatered.

The mixture of sludge and water enters the center of the elutriation tank, and the effluent or elutriate overflows a V-notched weir at the periphery of the tank. The elutriated sludge flows through 12-in. cast-iron pipes into two wells in the basement of the filter building. Each well contains a gravity-discharge, vertical elevator with a capacity that can be varied from 960 cu ft per hr to 3,840 cu ft per hr. The sludge from each elevator discharges into a rubber-lined steel coagulating tank, 12.5 ft by 1.67 ft in plan and 3.75 ft deep. The coagulated sludge from these tanks flows by gravity to any of the four vacuum filters.

Vacuum is applied to the filters by three pumps, one of which is for stand-by service. Each pump has a displacement of 2,000 cu ft per min. In the piping connecting the vacuum pumps with the filters there are two vacuum receivers and two moisture traps.

Compressed air is furnished the filters by three rotary-type blowers. Each blower delivers 750 cu ft per min of free air at a pressure of 2 lb per sq in. One blower is for stand-by service.

A horizontal belt conveyor with an ultimate capacity of 48 tons of filter cake per hr has been provided just below the operating floor of the building and between the four filters. This belt discharges just outside the building on a portable belt conveyor, which deposits the cake in a pile east of the building. Integral with the horizontal conveyor there are scales for weighing the cake automatically.

Facilities are provided in the vacuum filter building for coagulating the sludge by chlorinated copperas. It was decided to use this coagulant as copperas is quite cheap in Baltimore. In designing the equipment for making the chlorinated copperas it was assumed that 2.0 lb (anhydrous basis) per 100 lb of dry sludge solids would be required for coagulating purposes.

A rubber-lined steel mixing tank with an internal diameter of 9.42 ft and a depth of 6.83 ft was provided in the basement of the building for the reception of the copperas. The lining consists of a layer of hard rubber and a layer of soft rubber. The hard rubber protects the tank against the action of free chlorine. A motor-driven, propeller-type chemical unit mixes the contents of the tank.

Two centrifugal chemical pumps, each with a capacity of 100 gal per min, take their suction from the mixing tank and, after circulating the copperas through a system of rubber-lined piping, discharge it again into the tank. One of these pumps is used as a stand-by. Each pump is capable of circulating the contents of the mixing tank in 32 min. Dry chlorine gas is used to chlorinate the copperas. The gas is measured by a rotometer with a capacity ranging from 115 lb per day to 2,340 lb per day. Theoretically 100 lb of chlorine is necessary to oxidize, completely, 782 lb of $FeSO_4 \cdot 7H_2O$. During the early period of operation of the filter plant, dry chlorine gas was fed into the piping between the storage tank and the chemical pumps. The pumps mixed the chlorine gas and the copperas, and by the time the latter discharged into the storage tank the reaction between the two chemicals was completed. After trying this piping arrangement for several months better results were obtained by feeding the chlorine into the discharge piping from the chemical pumps.

The chlorine is stored in 1-ton cylinders in a room in the basement of the filter building. At one end of the room there is a platform scale capable of holding four 1-ton cylinders. A motor-driven centrifugal fan was installed to ventilate the two rooms containing the chlorine cylinders and the chlorinating equipment. This fan (which produces an air change every 2.6 min) takes its suction near the floor and discharges the air or chlorine fumes outside the building. Several push-button stations were installed at different points in the building for starting or stopping the fan quickly.

The chlorinated copperas, which is made in 3,260-gal batches, is stored in the basement in four rubber-lined steel tanks with a working capacity of 2,165 gal each. Two of these tanks were provided in 1939 when the original installation was made, and the other two were installed in 1946. On the main floor of the building there are six variable speed, diaphragm, acid resisting pumps each with a capacity of 1 gal per min, which take their suction from the chlorinated copperas storage tanks and discharge into the coagulating tanks. These pumps are arranged in two groups with three to a group, and are operated by one of the sludge elevators through a chain drive. In the original installation the coagulant was mixed with the sludge in the coagulating tanks by diffused air, blown through porous diffuser tubes. As this method of mixing proved unsatisfactory, the diffuser tubes were removed and replaced by one motor-driven propeller-type mixer in one tank and two mixers in the other. The mixers, which rotate at speeds of 34 rpm, are placed near the outlet end of each tank. The discharge end of the rubber hose from the coagulant pumps terminates just ahead of the propeller mixers. A glass indicator has been provided in each hose so that the operator can readily see if the coagulant is being pumped.

Electric Substation

Prior to the construction of the activated-sludge units 2,300-volt electric current was purchased from the local power company. At the time these units were being planned, it was realized that the demand for power would increase to 800 kw or more when they would go into operation. A demand of this magnitude warranted the installation of 33,000-volt incoming service, which is considerably cheaper than current purchased at the lower voltage. An electric substation, therefore, containing the necessary transformers and auxiliary equipment, was built.

This substation consists of a one-story brick building 53 ft by 21 ft in plan with a yard enclosed by a picket fence in the rear. Two 33,000-volt, three-wire, overhead power lines serve the station, one of which is for stand-by purposes. Each power line connects with a 34.5-kv, single-throw three-pole, air-break switch. In the yard at the rear of the building a 600-ampere oil circuit breaker and three 1,000-kva, single-phase, oil immersed (33,000/2,400) transformers were provided.

Inside the substation metal clad switchgear equipment has been installed for serving five outgoing, 2,300-volt feeders. Ultimately there will be six. Each feeder connects with two adjacent sections of the switchgear, each section housing an oil circuit breaker and its accessory equipment. There are two 2,300-volt buses, to either of which the load side of the circuit breakers can be

nnected. Suitable interlocks are provided so that the buses cannot be ıralleled.

Miscellaneous Items

Heating Facilities.—With the exception of the electric substation the six uildings described in this paper are heated by gas-fired unit heaters or gasred steam boilers. As a rule convector-type radiation enclosed in semirecessed ıbinets is installed in the smaller rooms and unit heaters are provided in the ırger rooms.

Plant Telephone System.—The sewage plant has been provided with a rivate telephone system for a number of years. This system was extended ɔ the six new buildings. A 24-pair, underground telephone cable was laid to ach building, in which a selective-ringing, selective-talking telephone set was ıstalled.

Construction Work

Practically all the work was done under twenty-five contracts, which varied ı amount from $6,273 to $873,064. A small part—the installing of the ıechanically cleaned screens, the laying of some of the electric conduits, and a ew minor items—was done by day labor.

Construction Cost

The total cost of constructing the treatment units exclusive of engineering xpense amounted to $3,859,500, divided as follows:

Mechanical Screen Building:	
Substructure	$ 16,029
Superstructure	33,620
Three screens	24,246
Total	$ 73,895
Three grit chambers	99,036
Five preliminary settling tanks	407,412
Activated-sludge units	1,001,819
Chlorinating equipment	6,490
Sludge control station	215,267
Five sludge digestion tanks	643,255
Gas holder	44,951
Vacuum filter installation	394,410
Electric substation	40,213
Grading	214,602
Sewer conduits	373,421
Sludge pipes	106,231
Gas pipes	22,862
Hot water pipes	49,079
Storm drains	34,982
Electric conduits and cables	42,922
Roads and sidewalks	14,015
Miscellaneous piping	62,706
Miscellaneous	11,932
Total	$3,859,500

The unit cost of the buildings and the tanks is given in Table 2. The cost of the buildings varied from $0.26 per cu ft for the mechanical screen building to $0.50 per cu ft for the blower house. The blower house was more expensive because it contained heavy expensive foundations, had a complete plumbing and heating system, and was provided with considerable miscellaneous equipment. The primary settling tanks, which varied in cost from $0.22 per cu ft to $0.28 per cu ft, were considerably cheaper than the final settling tanks

TABLE 2.—UNIT COSTS OF BUILDINGS AND OTHER STRUCTURES

Item	Year built	Total cost	Volume (cu ft)	Cost (cu ft)
Mechanical screen building	1931–1932	$49,569[a]	192,794	$0.26
Grit chamber building	1937–1938	11,548	26,431	0.44
Grit chambers	1937–1938	72,888[b]	67,500	1.08
Preliminary Settling Tanks:				
Nos. 1 and 2	1930–1931	163,638[b]	638,908	0.26
Nos. 3 and 4	1936–1937	149,493[b]	670,092	0.22
No. 5	1937–1938	94,281[b]	335,046	0.28
Activated-Sludge Units:				
Blower house	1938–1939	123,926[c]	248,604	0.50
Aeration tanks	1938–1939	488,836	667,543	0.73
Final settling tanks	1938–1939	127,812[b]	340,010	0.38
Sludge thickening tanks	1938–1939	18,201[b]	19,614	0.93
Sludge control station	1932–1933	74,202[c]	203,552	0.32
Sludge Digestion Tanks:				
Nos. 1 and 2	1933–1935	172,758[b]	401,200	0.43
No. 3	1937–1939	106,400[b]	200,600	0.53
Nos. 4 and 5	1946–1947	364,097[b]	401,200	0.91
Vacuum Filter Equipment:				
Filter building	1937–1939	128,707[d]	316,170	0.41
Elutriation tank	1937–1939	34,011[b]	98,458	0.35
Gas holder	1935	44,951	200,000	0.23
Electric substation	1939–1940	15,221[e]	32,380	0.47

[a] Does not include cost of screens. [b] Includes cost of mechanical equipment. [c] Does not include cost of mechanical and electrical equipment and pile foundation. [d] Does not include cost of mechanical and electrical equipment. [e] Does not include cost of electrical equipment.

which cost $0.38 per cu ft. Sludge digestion tanks 4 and 5, built after World War II, cost $0.91 per cu ft, which was 112% more than the cost of tanks 1 and 2 built from 1933 to 1935. The costs of the grit chambers, settling tanks, elutriation tank, sludge thickening tanks, and digesters also include the cost of the mechanisms in these tanks.

RESULTS ACCOMPLISHED

The additions and enlargements have materially improved the sewage plant. The odors produced by the plant have been greatly reduced as a result of the elimination of scum on the preliminary settling tanks. The disposal of screenings is no longer a problem, and the removal of grit from the sewage has eliminated, to a considerable extent, the deposition of this material in tanks and pipe lines.

The preliminary settling tanks produce a less acid sludge which is more amenable to digestion. Although the operation of the activated-sludge units has been handicapped by frequent sludge bulking, they have consistently produced an effluent containing less than 15 ppm of 5-day B.O.D. and suspended

solids. The heated sludge tanks under loadings of 0.17 lb of dry solids per cu ft per day have reduced the volatile content of the sludge an average of 50% in 15 days with the production of 10 cu ft of gas to 14 cu ft of gas per pound of volatile matter in the sludge.

During the 8-year period from 1940 to 1948, inclusive, the vacuum filters have dewatered sludge at an average rate of 4.64 lb of dry solids per square foot of filter area per hour with the use of 5.4 lb of chlorinated copperas per 100 lb of dry solids. The adoption of vacuum filters for the dewatering of sludge, in lieu of sludge drying beds, has resulted in a material reduction in the operating personnel, has permitted the drying of sludge throughout the year, and has decreased the production of odors. Chlorinating the final effluent during the warmer months of the year has afforded protection to the river against pathogenic organisms.

Engineering Organization

The engineering work was done under the general supervision of the following chief engineers of the Baltimore Department of Public Works: The late C. F. Goob (from 1927 to 1931), the late Bernard L. Crozier, M. ASCE (from 1931 to 1938), the late Frank K. Duncan, M. ASCE (from 1938 to 1939), the late George Cobb (from 1939 to 1943), and Nathan L. Smith, M. ASCE (from 1943 to 1947).

The director of the Department of Public Works since January 19, 1948, is Paul L. Holland, M. ASCE. The design and the construction work was under the direction of the following sewerage engineers of the Bureau of Sewers: Milton J. Ruark (from 1926 to 1931), George E. Finck, M. ASCE (from 1931 to 1947), and John J. Hunt (from 1947 to the present). The entire work was under the direct supervision of the writer. The firm of Whitman, Requardt and Associates designed the grit chambers and the activated-sludge units. The construction work was supervised by Edward R. Anderson (from 1930 to 1946) and Harold E. Burton (from 1946 to the present). Robert J. Trautman, Assoc. M. ASCE, has been connected with the work since 1930 and has served as associate engineer since January 1, 1945.